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Abstract: Forty male Merino lambs (6-8 wk old and 14.1 ± 0.20 kg body weight, BW) were used to compare the traditional feeding system for this animal, based on concentrate and long form barley supplied separately, with TMR pellets including different proportions of ground barley straw, for their effects on feed intake, animal performance and carcass and meat characteristics. Lambs were divided into four experimental groups (n = 10), each randomly assigned to one dietary treatment: Control (conventional system: long form barley straw and concentrate feed in separated feeding troughs), F05 (TMR pellet including 50 g barley straw/kg), F15 (TMR pellet including 150 g barley straw/kg) and F25 (TMR pellet including 250 g barley straw/kg). Lambs were fed the corresponding diet ad libitum. On days 22-26, feces and urine were collected from four animals per group. When animals reached 27 kg BW, they were slaughtered. Barley straw, total dry matter (DM), crude protein (CP), neutral detergent (NDF) and acid detergent (ADF) fiber and metabolizable energy intake linearly increased ($P < 0.001$) with the level of barley straw in the TMR. Dry matter digestibility decreased as barley straw in the diet increased, but NDF and ADF digestibility and N-balance were not affected ($P > 0.10$). F25 lambs had the greatest and F05 the smallest (P-linear = 0.002) values of average daily gain, but the feed to gain ratio was not significantly affected by the dietary treatments ($P = 0.172$). Abomasum-intestine content weight tended to increase with barley straw in the TMR (P-linear = 0.041). Neither carcass (carcass weight, chilling losses, dressing percentage, conformation, measurements, fat thickness or jointing into commercial cuts) nor meat characteristics (pH, fat and meat color, cooking losses and texture) were affected by the level of barley straw in the TMR ($P > 0.10$). Therefore, it is possible to fatten light lambs on a TMR pellet including ground barley straw by increasing average daily gain and reducing the duration of the fattening period, without a negative impact on carcass and meat characteristics; the optimal level of ground barley straw inclusion is around 150 g/kg TMR pellet.

# Concentrate plus ground barley straw pellets can replace conventional feeding systems for light fattening lambs

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**Abstract**

Forty male Merino lambs (6-8 wk old and 14.1 ± 0.20 kg body weight, BW) were used to compare the traditional feeding system for this animal, based on concentrate and long form barley supplied separately, with TMR pellets including different proportions of ground barley straw, for their effects on feed intake, animal performance and carcass and meat characteristics. Lambs were divided into four experimental groups (n = 10), each randomly assigned to one dietary treatment: Control (conventional system: long form barley straw and concentrate feed in separated feeding troughs), F05 (TMR pellet including 50 g barley straw/kg), F15 (TMR pellet including 150 g barley straw/kg) and F25 (TMR pellet including 250 g barley straw/kg). Lambs were fed the corresponding diet *ad libitum*. On days 22-26, feces and urine were collected from four animals per group. When animals reached 27 kg BW, they were slaughtered. Barley straw, total dry matter (DM), crude protein (CP), neutral detergent (NDF) and acid detergent (ADF) fiber and metabolizable energy intake linearly increased ($P < 0.001$) with the level of barley straw in the TMR. Dry matter digestibility decreased as barley straw in the diet increased, but NDF and ADF digestibility and N-balance were not affected ($P > 0.10$). F25 lambs had the greatest and F05 the smallest (P-linear = 0.002) values of average daily gain, but the feed to gain ratio was not significantly affected by the dietary treatments ($P = 0.172$). Abomasum-intestine content weight tended to increase with barley straw in the TMR (P-linear = 0.041). Neither carcass (carcass weight, chilling losses, dressing percentage, conformation, measurements, fat thickness or jointing into commercial cuts) nor meat characteristics (pH, fat and meat color, cooking losses and texture) were affected by the level of barley straw in the TMR ($P > 0.10$). Therefore, it is possible to fatten light lambs on a TMR pellet including ground barley straw by increasing average daily gain and reducing the duration of the fattening period, without a negative impact on carcass and meat characteristics; the optimal level of ground barley straw inclusion is around 150 g/kg TMR pellet.

**Keywords**

barley straw, carcass, lamb, performance, total mixed ration

## Introduction

In the Mediterranean countries, sheep meat production is derived from young animals (up to to 30 kg live weight, less than 5 months old), lighter and paler than that from the northern European regions (Sañudo et al., 1998, 2007). To promote great growth rates during this phase, the conventional feeding system is based in the supply of concentrated rations *ad libitum* supplemented with straw (usually from barley, coarsely chopped or in long form), which is an inexpensive source of fiber intended to mitigate the metabolic disorders, such as acidosis, associated to the high consumption of concentrates (Bodas et al., 2010; Rodríguez et al., 2008; Sañudo et al., 1998). Even though barley straw is supplied *ad libitum*, its consumption is usually below 10% of total dry matter intake (Bodas et al., 2010; López-Campos et al., 2011), and it requires a high storage capacity and increases labor costs, because this source of fiber must be supplied to the animals manually (Pérez Torres et al., 2011).

The use of rations devoid of barley straw has been already proposed, but the system has been demonstrated to be neither economically nor ecologically competitive, whereas the problems associated to the high concentrate intake still persist (Cooper et al., 1996; Rodríguez et al., 2007). The design of a feeding system based on the use of a concentrate pellet which includes a proportion of ground straw (total mixed ration –TMR- pellet) can be regarded as an interesting alternative to maintain this ingredient in the ration while avoiding the storage and distribution problems associated with its manipulation, because it would allow automatic delivery of the feed while reducing labor and storage costs, and hence farm profit would be increased. Thus, the use of TMR automatically delivered to the troughs for small ruminants has become the usual practice in dairy ewes and goats due to its reduced labor and storage costs (Pérez Torres et al., 2011; Tufarelli et al., 2011). However, these animals can consume thicker pellets than young lambs (thus allowing a larger forage grinding size) and forage contents is greater than the ratio required to maintain an optimal growth rate and lamb performance (Bodas et al., 2010; López-Campos et al., 2011; Sañudo et al., 1998).

The particle size or dietary physical effective fiber is an important influential factor for chewing activity, intestinal fiber and starch digestibility and ruminal pH (Zhao et al., 2009). Hence, the proportion of ground straw to be included in the pellet could be higher than the amount of long form straw that the animals consume in the conventional system, but must be kept within a limit, in order to maintain the superior performances in fattening lambs fed on diets based on concentrates (Bodas et al., 2007, 2009). Likewise, it is know that the level and way of supply of fiber in the diet has a clear effect on carcass and meat characteristics (Al-Saiady et al., 2010; Bas and Morand Fehr, 2000; Bodas et al., 2007, Normand et al., 2001), that must not be overlooked. Therefore, it will be necessary to determine the optimum level of straw that has to be included in the pellet.

To the best of our knowledge, there are no published studies comparing the conventional feeding system for light fattening lambs with an alternative one based on concentrate pellets including a ground forage source that can be fully automatically delivered to the animals. We hypothesize that the use of *ad libitum* concentrate plus ground barley straw pellets (TMR), which would ease feed management and distribution, is a suitable alternative to the conventional feeding system for light fattening lambs. Therefore, the objective of this study was to compare the latter (based on concentrate and long form barley supplied separately) with pelleted TMRs including different proportions of ground barley straw for their effects on feed intake, animal performance and carcass and meat characteristics.

## Material and methods

### *Animals and diets*

Forty male Merino lambs (6-8 wk old and mean BW 14.1 ± 0.20 kg at the beginning of the experiment) were used in this study. Lambs remained with their dams, with free access to commercial starter concentrate and alfalfa hay, and were treated to prevent white muscle disease (Vitasel, Lab. Ovejero, Spain), vaccinated against enterotoxemia (Miloxan, Merial Lab., Spain) and given an anthelmintic treatment (Ivomec, Merial Lab., Spain) before the commencement of the trial. After weaning and randomization on the basis of BW, each lamb was randomly allocated to one of four experimental treatments (n = 10), according to the feeding system: Control (conventional system: long form barley straw and concentrate pellet in separated feeding troughs), F05 (TMR pellet including 50 g barley straw/kg), F15 (TMR pellet including 150 g barley straw/kg) and F25 (TMR pellet including 250 g barley straw/kg). Lambs were housed in individual pens (one lamb per pen, with individual feeding and watering troughs), where they remained during the entire experimental period.

After five days of adaptation to the diets, each lamb was individually fed the corresponding experimental diet *ad libitum*; fresh drinking water was provided. The ingredients and chemical composition of the feeds are shown in Table 1. The amount of feed offered was adjusted daily on the basis of the previous day's intake, allowing refusals of ca. 200 g/kg feed offered. Samples of the feeds offered and orts were collected daily and pooled in weekly composites for each animal analyzed for DM content.

All handling practices followed the recommendations of the Directive 2010/63/EU of the European Parliament and of the Council on the protection of animals used for scientific purposes, and all of the animals used were able to see and hear the other sheep.

[Table 1]

*Feces and urine collection*

On day 19 of the experimental period, four lambs per treatment were confined to individual metabolism cages fitted with specific devices to collect feces and urine separately. The number of animals used was the minimum we considered necessary according to both statistical and welfare criteria. After two days of adaptation to the cages, feces and urine were collected for 5 days. The feces of each animal were collected daily, weighed, mixed thoroughly and sampled (10%). Aliquots from each lamb were pooled and stored at -30ºC until analysis. Urine was collected into a solution of $H_2SO_4$ (100 ml/l) to maintain the pH below 3. Daily urine was weighed, its density was measured and a sample (20%) from each lamb was taken. Daily samples were pooled to form composite samples and stored at -30ºC until analysis.

*Slaughter procedure*

Body weight was recorded twice a week, before the morning feeding, until the lambs reached the intended slaughter BW (27 kg BW). When an animal reached the intended BW, feed and water were withdrawn, and after 1 h the lamb was weighed again. The animal was immediately stunned and slaughtered by exsanguination from the jugular vein, eviscerated and skinned. The dressed carcass (Colomer-Rocher et al., 1988) was obtained from the whole body of each lamb and weighed. The carcass was chilled at 4ºC for 24 h and then weighed again; the chilling losses were calculated as the difference between hot (HCW) and cold carcass weights (CCW), expressed as a proportion of the initial HCW. The dressing percentage was calculated as CCW and expressed as the proportion of BW recorded just before slaughtering. Some carcass dimensions (carcass internal length (L), pelvic limb length (F) and buttock perimeter (B)) were measured and indices of carcass compactness (CCW/L, kg/cm) and leg compactness (G/F, g/cm) were calculated (Boccard et al., 1964). Carcass conformation, fatness score, consistency of fat, pelvic fat depot and meat and fat color were also assessed as described by Colomer-Rocher et al. (1988). The left side of each carcass was jointed into commercial cuts according to Colomer-Rocher et al. (1988); each joint was weighed to assess its proportion in the carcass.

*Rumen samples and digestive tract characteristics*

Once the white offal was obtained, full and empty weight of the reticulum-rumen-omasum and abomasum-intestine portions was recorded. Rumen fluid samples from each animal were collected and strained through two layers of cheese cloth and the pH was determined.

*Meat measurements*

Meat quality was evaluated in the M. *longissimus thoracis et lumborum* (LTL) of the left half carcass. Thus, at 0 and 45 min post-mortem, pH was measured on the sixth rib using a pHmeter (Metrohm, Zofingen, Switzerland), equipped with a penetrating electrode and a temperature probe. At 24 h, the rib joint (from the sixth rib-onwards) was cut at the level of the 13$^{th}$ rib, and pH and color were measured at the sixth rib site. The CIELAB system (Commission Internationale de l'Eclairage, 1986) was used to determine color parameters using a Minolta CM-2002 chromameter (Konica-Minolta Sensing, Inc., Germany). Chroma and Hue were calculated using CIE L*a*b* coordinates (D65, 10º). The LTL was dissected and weighed and a subsample of M. *longissimus lumborum* was stored at -30 ºC until cooking losses and instrumental texture measurements were performed. The cooking losses were calculated on thawed meat samples, by cooking in a 75 ºC water bath until the center of the sample reached 70 ºC. Cooked muscle cores with a cross section of 10 mm$^2$ and 20 mm in length were cut parallel to the muscle fibers and the shear force was measured using a Warner-Bratzler device mounted on a Texture Analyzer QTS 25 (CNS Farnell, Borehamwood, UK). M. *longissimus lumborum* was stored at -30ºC until the chemical analyses were performed.

*Analytical procedures*

The procedures described by AOAC (2003) were used to determine DM, ash and CP content in the feed, feces and M. *longissimus thoracis* samples. ADF and NDF were determined in feed samples using the method of Van Soest et al. (1991).

*Calculations and statistical analysis*

Average daily weight gain was estimated as the regression coefficient (slope) of BW against time using the REG procedure of the SAS package (SAS Inst. Inc., Cary, NC). The data were subjected to analysis of variance with the diet as the fixed effect and the animal as the random effect, using the MIXED procedure of SAS. Animal was considered as the experimental unit, thus allowing 10 replicates for each treatment. Linear and quadratic contrasts for F05, F15 and F25 groups were used to test the effects of level of barley straw inclusion.

**Results**

Total DM intake increased with the level of inclusion of barley straw in the TMR, with F05 and Control lambs having the lowest values of total dry matter (DM), crude protein (CP), neutral detergent fiber (NDF), acid detergent fiber (ADF) and metabolizable energy intake (Table 2, $P < 0.001$). Barley straw intake (measured in the feeding trough or calculated from TMR composition and intake) significantly increased with the level of inclusion ($P < 0.001$), Control lambs had the lowest values, whereas concentrate intake was the same for all groups ($P = 0.939$). Barley straw, total DM, CP, NDF, ADF and metabolizable energy intake increased linearly with the level of barley straw in the TMR ($P < 0.001$).

DM digestibility decreased as the level of inclusion of barley straw in the diet increased, with Control lambs showing intermediate values between F05 and F15 animals ($P = 0.006$). Values of NDF and ADF digestibility and N-balance were not affected by barley straw inclusion ($P > 0.10$). As for animal performance, F25 had the greatest and F05 the lowest values of average daily gain ($P = 0.003$; P-linear = 0.002), which led to the tendency of F25 animals to have the shortest and F05 animals to have the longest duration of the fattening period ($P = 0.050$; P-linear = 0.013). Feed to gain ratio was not significantly affected by dietary treatments ($P = 0.172$).

[Table 2]

The empty weight of the rumen-reticulum-omasum and abomasum-intestine portions was not affected by barley straw inclusion (P > 0.10, Table 2), nor was rumen content weight. However, abomasum-intestine content weight tended to increase with barley straw in the TMR (P = 0.086; P-linear = 0.041).

[Table 3]

Cold carcass weight, chilling losses and dressing percentage were not significantly affected by dietary treatments (P > 0.10). None of the carcass characteristics studied (carcass conformation, measurements, fat thickness or jointing into commercial cuts; Table 4) were affected by the level of addition of barley straw to the TMR (P > 0.10).

[Table 4]

Table 5 shows that data regarding meat characteristics (pH, fat and meat color, cooking losses and texture) were not significantly affected by dietary treatments (P > 0.10).

[Table 5]

**Discussion**

The use of TMR compared to supplying concentrate and barley straw separately presents the advantage of reducing feed manipulation, feeding time and labor costs. Although TMR have been (and still are) extensively used for dairy sheep, their use in fattening lambs is still incipient, based on forages of higher quality than barley straw and with proportions of forage higher than those used in the present study (Tufarelli et al., 2011).

Finishing ruminants such as fattening lambs are fed high concentrate diets to promote high daily gains (Mialon et al., 2008). This kind of diet can depress ruminal pH (Mould and Orskov, 1983), and a minimum level of fiber in the diet is needed to avoid digestive disorders, such as acidosis (Giger-Reverdin and Sauvant, 1991; Sauvant et al., 1999). The objective of including forage in the TMR is to supply a diet with a high proportion of cereal grains to maximize energy intake while maintaining ruminal activity.

In the present study, as barley straw increased in the TMR pellets, there was an increase in total DM intake. Even though there are no studies in light lambs, these results are in line with the findings of Papi et al. (2011), who carried out an experiment with lambs heavier (from 38 to 60 kg LBW) than those used in the present experiment (from 14 to 27 kg LBW) and reported an increase in DM intake as the forage proportion increased in the diet. Previous studies (using animals from 30 to 36 kg LBW) have also reported increasing effects of high forage diets on DM intake (McLeod and Baldwin, 2000). In the present study, total DM intake increased while the level of intake of the concentrated part of the TMR pellets (calculated by subtracting the corresponding barley straw intake from the total TMR intake) was constant, which can be interpreted as an attempt to maximize ME intake. This fact would support the idea that animals eat food mainly to satisfy their desire for energy (Van Soest et al., 1984). It is noteworthy that those animals in the Control group, which received barley straw *ad libitum*, showed a barley intake proportion of 3.3 % of total DM intake, which is quite close to that of group F05. Additionally, animals from these two groups had similar DM and ME intakes.

In contrast to our results, other authors have reported decreases in average daily gain of kids and lambs as forage increased in the diet (Carrasco et al., 2009*a*; Johnson et al., 2010; Papi et al., 2011; Tufarelli et al., 2011), but the lowest level of forage used in these diets was higher than the highest one used in the present study (25%). In our study, all the animals maximized ME intakes, which allowed them to express their potential and maximize growth rates. Likewise, the higher DM intakes shown by lambs in the F15 and F25 groups gave raise to higher average daily gains and a shorter duration of the fattening period than Control or F05 lambs.

Despite the lack of statistically significant differences, the feed to gain ratio was a 10% worse for F25 lambs, with F15 and Control lambs showing the best values, which agrees with previous studies pointing out a decrease in animal performance as forage in the diet increased (Carrasco et al., 2009*a*; Tufarelli et al., 2011).

The level of forage in the diet is widely known to affect digestibility, and as the level of concentrate in the diet increases, so does DM and OM digestibility (Archimède et al., 2008; Cantalapiedra-Hijar, 2009). However, the effect of the F:C ratio on digestibility of other components is still controversial, with some researchers suggesting that CP digestibility might be not affected (Molina-Alcaide et al., 2000) or even increased (Ramanzin et al., 1997), while fiber digestibility is usually reduced (Castrillo et al., 1995). The results of the present study, however, show no differences in fiber or CP digestibility due to the level of forage in the diet, while DM digestibility significantly decreased with increased barley straw proportion in the TMR pellet. This decrease in DM digestibility has been previously observed in other experiments where a source of fiber was added to a high-concentrate diet, because of the low digestibility of the fibrous part of the diet, which would accordingly reduce DM digestibility (Castrillo et al., 1995; Cecava et al., 1991; Haddad, 2005).

It is important to say that, in the present study, despite the increase in straw intake, differences in ruminal pH values (5.57 ± 0.076) were not observed, nor were clinical symptoms of acidosis, which suggests that lambs likely did not experience discomfort due to decreased ruminal pH (Commun et al., 2009). It must be taken into account, however, that these values were taken just after slaughter and, therefore, are not indicative of variations along day

A high level of barley straw intake, and hence of fiber, could also reduce the efficiency of ME for tissue gain, because of an elevation in heat production (Reynolds et al., 1991) or in the weight of the portal drained viscera (McLeod and Baldwin, 2000). Some authors have suggested that gastro-intestinal tract weight increases with the use of high forage diets, which would eventually be reflected in a reduced dressing percentage (Carrasco et al., 2009*a*; Papi et al., 2011). However, in our study, despite the numerical differences observed in digestive tract weight, there were no significant effects of diet on this parameter (even when it was expressed as a proportion of live or empty body weight), with the exception of the abomasum-intestine, which increased with the level of barley straw in the diet. Although the relatively short duration of the fattening period could have diminished the differences in gastrointestinal tract weight, variations in the forage content of the diet have an effect on this parameter due to differences in ME intake (McLeod and Baldwin, 2000). Groups in the present study differed in terms of forage intake, but it must be pointed out that the highest level used in this study is lower than that in studies reporting differences in digestive tract weight (McLeod and Baldwin, 2000; Carrasco et al., 2009*a*; Papi et al., 2011).

The values of carcass traits observed in the present study are within the range of those reported in the literature for lambs of similar characteristics (Carrasco et al., 2009*a*; Bodas et al., 2010; López-Campos et al., 2011). The feeding system and the level of forage is known to affect carcass characteristics (Zervas and Tsiplakou, 2011), but the main differences are observed between extreme concentrate to forage ratios (fed indoors on concentrate vs. fed outdoors on pasture) (Carrasco et al., 2009*a*; Joy et al., 2008). The level of forage and the characteristics of the diets used in the current study did not cause significant differences in carcass weight or conformation. Previous studies have shown that the use of high forage diets for finishing lambs usually produces a carcass with a slightly inferior conformation and fatness score and a low amount of fat depots, which is directly related to energy intake (Carrasco et al., 2009*a*; Joy et al., 2008). In the present study, however, all the lambs were fed *ad libitum* and had high ME intakes. Moreover, the diets offered to the animals were isonitrogenous, which caused an increase in CP intake as discussed previously. Thus, CP and ME intake was high enough so that all the lambs had the desired carcass conformation and fatness score.

Likewise, the lack of differences in the proportion of the commercial joints is in concordance with the results observed for the other carcass characteristics and agrees with previous studies (Carrasco et al., 2009*a*). When lambs with similar characteristics to those in the present study were slaughtered at a fixed live weight, commercial joint proportions were more affected by slight variations in the slaughter weight than for the feeding system applied to the lambs (Carrasco et al., 2009*a*). Only when feeding systems are completely different (fed indoors on concentrate vs. fed outdoors on pasture) and when animals are slaughtered at a fixed age, differences in carcass characteristics (undesriable carcass conformation, reduced fatness, changes in the proportion of commercial joints) are likely to appear (Jabar and Anjum, 2008; Joy et al., 2008; Papi et al., 2011).

The values of meat traits studied in the present work are within those reported by Díaz et al. (2002), López-Campos et al. (2011) or Sañudo et al. (1997) for lambs raised under similar conditions. Feeding systems and the level of forage in the diet may affect these parameters, in particular when high proportions of forage (even good quality forage) are used and energy intake and growth rate are affected (Carrasco et al., 2009*b*; Joy et al., 2008; Zervas and Tsiplakou, 2011). In the present study, ground straw inclusion did not reduce energy intake or average daily gain, which could help to explain the lack of differences. Additionally, the effects of feeding systems on some meat traits, such as cooking losses, are usually due to differences in fat cover, whereas the differences in texture parameters are more difficult to explain, as the results from different studies are sometimes contradictory (Carrasco et al., 2009*b*).

**Conclusions**

Increasing proportions of ground barley straw (up to 250 g/kg) in the TMR pellet for light fattening lambs increase ADG and reduce duration of the fattening period without affecting carcass characteristics. Animals receiving 50 g barley straw/kg TMR pellet showed the longest duration of the fattening period and the lowest ADG values. On the other hand, the improvements achieved using 250 g barley straw/kg TMR pellet were not beyond those obtained with 150 g barley straw/kg TMR pellet. . Therefore, the results of the present study suggest that it is possible to successfully fatten light lambs on a feeding system based on TMR pellet that can be automatically delivered, while increasing ADG and reducing the duration of the fattening period without a negative impact on carcass and meat characteristics. The ideal level of barley straw inclusion is around 150 g/kg TMR pellet.

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**Table 1.** Ingredients and chemical composition of the experimental feeds and the barley straw.

| | Control | F05 | F15 | F25 | Barley straw |
|---|---|---|---|---|---|
| Ingredients (g/kg) | | | | | |
| Barley | 530 | 490 | 433 | 388 | |
| Corn | 230 | 210 | 150 | 80 | |
| Soybean meal 44 | 210 | 220 | 237 | 252 | |
| Barley straw | -- | 50 | 150 | 250 | |
| Mineral vitamin mix | 30 | 30 | 30 | 30 | |
| Chemical composition (g/kgDM) | | | | | |
| NDF | 166 | 196 | 259 | 323 | 626 |
| ADF | 58 | 59 | 94 | 138 | 413 |
| CP | 182 | 181 | 181 | 181 | 47 |
| Ash | 63 | 60 | 73 | 83 | 104 |
| Metabolizable energy (kcal/kg DM)[1] | 2744 | 2662 | 2495 | 2328 | 1200 |

[1]Calculated from feed composition tables (FEDNA, 2010).

**Table 2.** Mean values of DM, CP, NDF and ADF intake and digestibility, metabolizable energy intake, average daily gain, length of fattening period and feed to gain ratio of lambs receiving concentrate and barley straw separately (Control) or a TMR with 50, 150 and 250 g barley straw per kg (F05, F15 and F25, respectively).

| | **Control** | **F05** | **F15** | **F25** | **s.e.m.** | **P-value** | **LIN** | **QUA** |
|---|---|---|---|---|---|---|---|---|
| Intake (g/animal and day) | | | | | | | | |
| Concentrate DM[1] | 790 | 797 | 779 | 792 | 20.9 | 0.939 | 0.877 | 0.511 |
| Barley straw DM[2] | 27$^{a}$ | 40$^{b}$ | 138$^{c}$ | 264$^{d}$ | 4.1 | <0.001 | <0.001 | 0.012 |
| Total DM | 817$^{a}$ | 796$^{a}$ | 916$^{b}$ | 1056$^{c}$ | 74.0 | <0.001 | <0.001 | 0.728 |
| CP | 145$^{a}$ | 148$^{a}$ | 166$^{b}$ | 191$^{c}$ | 13.4 | <0.001 | <0.001 | 0.469 |
| NDF | 148$^{a}$ | 160$^{a}$ | 237$^{b}$ | 341$^{c}$ | 18.9 | <0.001 | <0.001 | 0.094 |
| ADF | 57$^{a}$ | 51$^{a}$ | 86$^{b}$ | 146$^{c}$ | 7.7 | <0.001 | <0.001 | 0.001 |
| Metabolizable energy (kcal/animal and·day) | 2201$^{a}$ | 2122$^{a}$ | 2286$^{a}$ | 2459$^{b}$ | 188.4 | 0.002 | <0.001 | 0.941 |
| Digestibility coefficients (g/g) | | | | | | | | |
| DM | 0.79$^{ab}$ | 0.82$^{a}$ | 0.76$^{bc}$ | 0.71$^{c}$ | 0.011 | 0.006 | 0.281 | 0.074 |
| CP | 0.73 | 0.78 | 0.77 | 0.75 | 0.014 | 0.428 | 0.247 | 0.264 |
| NDF | 0.38 | 0.40 | 0.39 | 0.41 | 0.035 | 0.983 | 0.875 | 0.842 |
| ADF | 0.36 | 0.31 | 0.33 | 0.35 | 0.038 | 0.926 | 0.753 | 0.634 |
| Nitrogen balance (g/animal and day) | 14.5 | 14.2 | 17.1 | 20.9 | 1.29 | 0.127 | 0.395 | 0.522 |
| Average daily gain (g/day) | 299$^{ab}$ | 280$^{a}$ | 339$^{ab}$ | 353$^{b}$ | 14.7 | 0.003 | 0.002 | 0.236 |
| Duration of the fattening period (days) | 44.4$^{ab}$ | 46.8$^{a}$ | 39.9$^{ab}$ | 37.6$^{b}$ | 2.47 | 0.050 | 0.013 | 0.451 |
| Feed:gain (g/g) | 2.76 | 2.89 | 2.74 | 3.03 | 0.103 | 0.172 | 0.389 | 0.117 |

s.e.m. = Standard error of the mean; LIN and QUA = Linear and quadratic contrasts for F05, F15 and F25 groups.

[1]Concentrate: Supplied in the feeding trough (Control lambs) or the portion of TMR that is not barley straw (F05, F15 and F25 animals).

[2]Barley straw intake, measured as ingested from the feeding trough (Control lambs) or calculated from TMR composition (F05, F15 and F25 lambs).

[a, b, c, d]Within the same row, different letters indicate significant differences for the comparison of all the groups ($P < 0.05$).

**Table 3.** Mean weight of empty digestive tract (reticulum-rumen, omasum, abomasum-intestine) and digestive tract contents of lambs receiving concentrate and barley straw separately (Control) or a TMR with 50, 150 and 250 g barley straw per kg (F05, F15 and F25, respectively).

| | **Control** | **F05** | **F15** | **F25** | **s.e.m.** | **P-value** | **LIN** | **QUA** |
|---|---|---|---|---|---|---|---|---|
| Digestive tract contents weight (g) | | | | | | | | |
| Rumen-reticulum-omasum | 2634 | 2549 | 2613 | 2642 | 159.1 | 0.976 | 0.701 | 0.934 |
| Abomasum-intestine | 1593 | 1529 | 1769 | 1799 | 85.6 | 0.086 | 0.041 | 0.346 |
| Total | 2456 | 2582 | 2660 | 2628 | 60.3 | 0.104 | 0.613 | 0.476 |
| Empty digestive tract weight (g) | | | | | | | | |
| Rumen-reticulum-omasum | 788 | 903 | 868 | 844 | 36.2 | 0.169 | 0.316 | 0.918 |
| Abomasum-intestine | 1668 | 1679 | 1792 | 1784 | 53.0 | 0.216 | 0.183 | 0.369 |
| Total | 4227 | 4078 | 4381 | 4441 | 185.8 | 0.518 | 0.187 | 0.604 |
| Total/empty body weight (g/kg) | 107.8 | 112.0 | 115.8 | 115.4 | 2.62 | 0.128 | 0.378 | 0.526 |

s.e.m. = Standard error of the mean; LIN and QUA = Linear and quadratic contrasts for F05, F15 and F25 groups.

**Table 4.** Mean values of carcass characteristics of lambs receiving concentrate and barley straw separately (Control) or a TMR with 50, 150 and 250 g barley straw per kg (F05, F15 and F25, respectively).

| | **Control** | **F05** | **F15** | **F25** | **s.e.m.** | **P-value** | **LIN** | **QUA** |
|---|---|---|---|---|---|---|---|---|
| Cold carcass weight (CCW, kg) | 12.0 | 12.3 | 12.0 | 12.1 | 0.21 | 0.853 | 0.555 | 0.596 |
| Chilling losses (%) | 2.47 | 2.64 | 2.50 | 2.66 | 0.134 | 0.698 | 0.915 | 0.402 |
| Dressing percentage | 44.5 | 45.1 | 44.0 | 44.3 | 0.62 | 0.615 | 0.380 | 0.327 |
| Kidney knob and cannel fat (g) | 156 | 178 | 139 | 182 | 17.3 | 0.279 | 0.878 | 0.101 |
| Carcass conformation (1, poor to 5, excellent) | 3.1 | 2.9 | 2.7 | 2.8 | 0.23 | 0.630 | 0.677 | 0.630 |
| Fatness score (1, very lean to 4, very fat) | 2.4 | 2.1 | 2.5 | 2.1 | 0.64 | 0.340 | 1.000 | 0.097 |
| Meat color (1, white to 5, intense red) | 2.6 | 2.4 | 2.8 | 2.6 | 0.23 | 0.794 | 0.580 | 0.360 |
| Pelvic fat (1, lean to 3, very fat) | 1.7 | 1.7 | 1.5 | 1.4 | 0.68 | 0.737 | 0.409 | 0.946 |
| Fat color (1, white to 5, yellow) | 2.4 | 2.8 | 2.5 | 2.8 | 0.18 | 0.444 | 1.000 | 0.217 |
| Consistency of fat (1, firm to 3, soft) | 1.3 | 1.0 | 1.2 | 1.5 | 0.46 | 0.179 | 0.043 | 0.729 |
| Pelvic limb length (F, cm) | 28.1 | 28.0 | 27.2 | 28.1 | 0.55 | 0.587 | 0.889 | 0.178 |
| Carcass internal length (L, cm) | 56.1 | 55.8 | 55.8 | 55.2 | 0.45 | 0.566 | 0.453 | 0.607 |
| Buttock perimeter (cm) | 54.2 | 55.0 | 58.2 | 54.4 | 2.13 | 0.523 | 0.875 | 0.256 |
| Subcutaneous fat thickness (mm) | 1.32 | 1.42 | 1.52 | 1.23 | 0.175 | 0.677 | 0.444 | 0.373 |
| Commercial cuts (%) | | | | | | | | |
| Shoulder | 20.1 | 20.2 | 19.8 | 20.4 | 0.32 | 0.656 | 0.723 | 0.235 |
| Loin-rib | 15.3 | 17.0 | 15.6 | 15.7 | 0.66 | 0.317 | 0.160 | 0.373 |
| Best-end | 5.1 | 5.1 | 5.2 | 4.7 | 0.36 | 0.768 | 0.300 | 0.495 |
| Tail | 1.4 | 1.3 | 1.1 | 1.4 | 0.10 | 0.360 | 0.440 | 0.180 |
| Scrag-end | 9.7 | 9.3 | 9.6 | 9.1 | 0.22 | 0.151 | 0.607 | 0.108 |
| Breast-flank | 11.4 | 10.6 | 12.0 | 11.4 | 0.39 | 0.116 | 0.148 | 0.056 |
| Leg | 37.0 | 36.6 | 36.7 | 37.4 | 0.52 | 0.700 | 0.239 | 0.552 |
| Carcass compactness index (CCW/L, kg/cm) | 0.215 | 0.220 | 0.216 | 0.219 | 0.0037 | 0.768 | 0.898 | 0.457 |
| Leg compactness index (Leg weight/F, g/cm) | 77.7 | 79.3 | 80.0 | 79.5 | 2.03 | 0.859 | 0.964 | 0.792 |
| Fat color | | | | | | | | |
| L* | 66.3 | 66.3 | 67.3 | 65.8 | 1.08 | 0.787 | 0.718 | 0.367 |
| a* | 3.2 | 3.3 | 2.8 | 3.4 | 0.36 | 0.629 | 0.825 | 0.241 |
| b* | 14.9 | 14.2 | 16.0 | 16.5 | 0.88 | 0.260 | 0.084 | 0.541 |

s.e.m. = Standard error of the mean; LIN and QUA = Linear and quadratic contrasts for F05, F15 and F25 groups.

**Table 5.** Mean values of meat characteristics of lambs receiving concentrate and barley straw separately (Control) or a TMR with 50, 150 and 250 g barley straw per kg (F05, F15 and F25, respectively).

| | **Control** | **F05** | **F15** | **F25** | **s.e.m.** | **P-value** | **LIN** | **QUA** |
|---|---|---|---|---|---|---|---|---|
| pH | | | | | | | | |
| 0 h | 6.44 | 6.41 | 6.53 | 6.54 | 0.037 | 0.093 | 0.071 | 0.357 |
| 45 min | 6.12 | 6.21 | 6.27 | 6.29 | 0.065 | 0.292 | 0.414 | 0.817 |
| 24 h | 5.75 | 5.75 | 5.72 | 5.72 | 0.058 | 0.969 | 0.746 | 0.861 |
| Meat color (1, white to 5, intense red) | 2.6 | 2.4 | 2.8 | 2.6 | 0.23 | 0.794 | 0.580 | 0.360 |
| *Rectus abdominis* color | | | | | | | | |
| L* | 49.9 | 48.8 | 50.5 | 48.4 | 1.14 | 0.574 | 0.811 | 0.236 |
| a* | 8.9 | 8.0 | 8.3 | 8.6 | 0.47 | 0.560 | 0.352 | 0.946 |
| b* | 12.0 | 9.9 | 13.5 | 12.8 | 1.51 | 0.375 | 0.176 | 0.263 |
| *Longissimus dorsi* characteristics | | | | | | | | |
| Color | | | | | | | | |
| L* | 37.8 | 37.4 | 37.7 | 36.4 | 0.63 | 0.420 | 0.312 | 0.358 |
| a* | 8.6 | 8.2 | 8.2 | 8.4 | 0.52 | 0.947 | 0.795 | 0.919 |
| b* | 19.1 | 16.1 | 20.0 | 20.7 | 1.58 | 0.229 | 0.046 | 0.417 |
| Cooking losses (%) | 24.6 | 25.5 | 25.1 | 23.1 | 0.90 | 0.365 | 0.117 | 0.527 |
| Texture | | | | | | | | |
| Shear force (kg) | 72.9 | 75.3 | 74.5 | 74.7 | 4.54 | 0.987 | 0.937 | 0.941 |
| Area (kg/s) | 640 | 592 | 597 | 637 | 54.8 | 0.899 | 0.579 | 0.803 |
| Chemical composition (g/kg meat) | | | | | | | | |
| DM | 228.2 | 229.1 | 229.2 | 226.7 | 2.13 | 0.824 | 0.450 | 0.620 |
| Ash | 16.6 | 17.0 | 15.7 | 16.0 | 1.33 | 0.898 | 0.594 | 0.607 |
| CP | 193.5 | 195.1 | 195.9 | 194.7 | 2.25 | 0.891 | 0.882 | 0.710 |
| Ether extract | 18.2 | 16.9 | 17.6 | 16.0 | 1.50 | 0.750 | 0.671 | 0.534 |

s.e.m. = Standard error of the mean; LIN and QUA = Linear and quadratic contrasts for F05, F15 and F25 groups.